Name:	Date:

Topic 2.2 Adaptations for Gas Exchange – Page 1

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the adaptations for gas exchange which allow an increase in body size and metabolic rate

(b) gas exchange in small animals across their general body surface

(c) the comparison of gas exchange mechanisms in *Amoeba*, flatworm and earthworm

(d) the common features of the specialised respiratory surfaces of larger animals and the adaptation of respiratory surfaces to environmental conditions - fish have gills for aquatic environments and mammals have lungs for terrestrial environments

(e) the need for large active animals with high metabolic rates to have ventilating mechanisms to maintain gradients across respiratory surfaces

(f) ventilation in bony fish and comparison of counter current flow with parallel flow

(g) the structure and function of the human breathing system, including examination of microscope slides of T.S. lung and trachea

(h) ventilation in humans and how gases are exchanged

(i) the adaptations of the insect tracheal system to life in a terrestrial environment

(j) the structure of the angiosperm leaf

(k) the role of leaf structures in allowing the plant to function and photosynthesise effectively

(l) the role of the leaf as an organ of gaseous exchange, including stomatal opening and closing

SPECIFIED PRACTICAL WORK

- Investigation into stomatal numbers in leaves
- Dissection of fish head to show the gas exchange system
- Scientific drawing of a low power plan of a prepared slide of T.S. dicotyledon leaf e.g. *Ligustrum* (privet), including calculation of actual size and magnification of drawing

Prior to AS level you probably only looked at gas exchange in human lungs and probably gas exchange across a plant leaf surface. In this unit you will look at the problems that organisms face as they get larger and the different challenges posed by an aquatic compared to a terrestrial environment.

		Completed
1.	Complete the worksheet 'Explaining the need for specialised gas exchange surfaces and ventilation' page 4 & 5	
2.	Read page 6 and answer the following: • Summarise the problems faced by aquatic and terrestrial environments when it comes to as exchange. • Why do large multicellular organisms require specialised gas exchange surfaces? • List 4 features that all gas exchange surfaces should have and explain why.	
3.	Read page 8 about gas exchange in an earthworm and answer the question on the page.	
4.	Read page 9 about gas exchange in insects and answer the questions. • Watch the videos on the locust • If an insect's body starts to produce lactic acid, explain what will happen to the fluid at the ends of the tracheoles and how this will aid gas exchange.	
5.	Read pages 10-13 about gas exchange in bony fish and cartilaginous fish. Answer the following: • Name 3 structural features of fish gills, which make them efficient gas, exchange surfaces. • Draw diagrams to help explain the counter current system that helps with gas exchange in bony fish. Complete the data analysis and table on page 13.	
6.	Read Toole and Toole Understanding Biology Textbook p392-400	

End of topic checklist for 2.2 Adaptations for Gas Exchange
Tick as appropriate:
RED: I do not know about this
AMBER: I have heard about this but have not learned this yet. I am unsure on this.
GREEN: I have heard about this and I have learned this. I am confident about this.

Topic	RED	AMBER	GREEN
1. Living things need to obtain materials such as carbon dioxide and oxygen from the environment and remove waste from their cells to the environment.			
2. Requirements may be proportional to volume however; diffusion is proportional to surface area.			
3. In large organisms the surface area to volume ratio is much less than in smaller organisms.			
4. In small, unicellular organisms the surface area to volume ratio is so large that diffusion through the body surface is sufficient to meet their needs. Know an example as the amoeba.			
5. Also, distances within the body are small and transport by diffusion is again sufficient to supply needs.			
6. Larger, multicellular organisms may have a surface area to volume area, which is too small to supply all their needs.			
7. These organisms therefore possess special for gaseous exchange, gills for aquatic environments, and lungs for terrestrial.			
8. These exchange surfaces have particular properties to aid diffusion; large surface area and thin, permeable surface.			
9. The large moist area for gaseous exchange is a region of potential water loss.			
10. Earthworms are multicellular, terrestrial animals restricted to damp areas. A moist body surface for diffusion, with a circulatory system and blood pigments, increase efficiency of gaseous exchange sufficient for a slow moving animal.			
11. Bony fish are larger and more active. Their needs are supplied by a specialised area, the gills, with a large surface extended by gill filaments.			
12. Water is a dense medium with a low oxygen content; therefore, to increase efficiency, it needs to be forced over the gill filaments by pressure differences so maintaining a continuous unidirectional flow of water.			
13. The gills have an extensive network of blood capillaries to allow efficient diffusion and haemoglobin for oxygen carriage.			
14. Compared with parallel flow, counter current flow increases efficiency because the diffusion gradient between the adjacent flows is maintained over the whole surface.			
15. Terrestrial vertebrates have adapted for exchange with air, a less dense medium, so have internal lungs.			
16. Internal lungs minimise loss of water and heat.			
17. Amphibians have a larval form (tadpole) which develops in water and undergoes metamorphosis in the adult form.			
18. The inactive frog uses its moist skin as a respiratory surface but when active uses lungs.			
19. Reptiles and birds have more efficient lungs than			

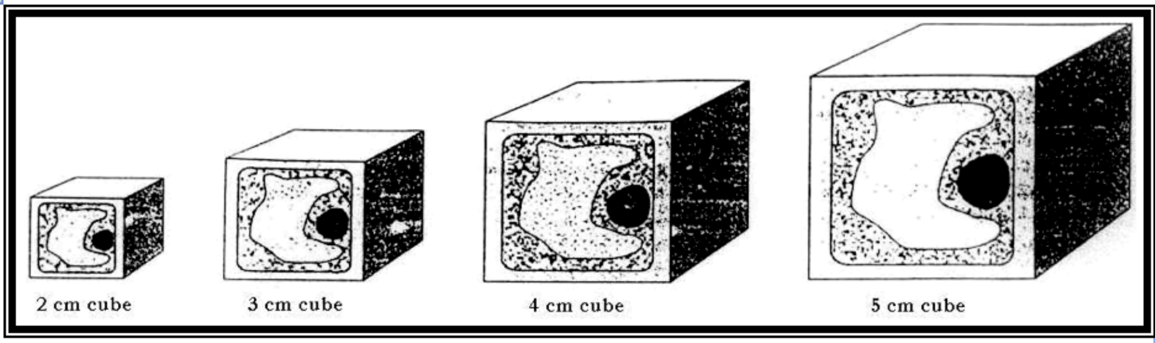
amphibians.			
20. The human respiratory system includes epiglottis, trachea, bronchi, bronchioles, alveoli, pleural membranes and cavity, ribs, intercostal muscles and diaphragm. There are involved in two functions ventilation and gas exchange.			
21. The intercostal muscles, diaphragm, pleural membranes and cavity allow ventilation movements to take place, creating volume and pressure changes that allow a continuous exchange of gases inside the body, so maintaining concentration gradients.			
22. Insects have evolved a different system of gaseous exchange to other land animals.			
23. Insects possess a branched, chitin-lined system of tracheae with openings called spiracles.			
24. Plants rely entirely on diffusion for the exchange of gases. Leaves are therefore thin to shorten distances for diffusion, have a large surface area and are permeated with air spaces.			
25. The structure of the angiosperm leaf includes the cuticle, epidermis, palisade mesophyll, spongy mesophyll, vascular bundle, air spaces, stomata and guard cells. These structures allow the plant to photosynthesise effectively.			
26. Leaf adaptations for light harvesting include a large surface area and the ability to move by growth to the best position.			
27. Palisade cells are elongated and densely arranged in a layer, or layers and they contain many chloroplasts, which arrange themselves according to the light intensity.			
28. Light can pass through to the spongy mesophyll. The spaces between the spongy mesophyll cells allows carbon dioxide to diffuse to the cells and oxygen can diffuse away. The cells are moist so gases can dissolve.			
29. Leaves have a cuticle to prevent water loss which also reduces gaseous exchange.			
30. The presence of pores, stomata, allows gases through.			
31. Guard cells around the stomata can change shape to open and close the stomata so helping to control gas exchange and water loss.			
32. Guard cells change shape because of changes in turgor; in light water flows in by osmosis so the guard cells expand.			
33. The inner wall is inelastic so the pairs of cells curve away from each other and the pores open.			
34. Pores close due to the reverse process.			
35. There are several theories about the mechanism and opening is affected by changing CO2 levels, but only the malate theory is required. The movement of K+ ions from the epidermal cells into the guard cells creates negative water potential in the guard cells. Water moves in by osmosis.			
36. The movement of K+ ions is an active process requiring ATP.			
37. Xerophytes may open stomata at night instead of during the day in order to conserve water, whilst other plants may close stomata during the day or night under drought conditions.			

Gas Exchange

During aerobic respiration, mitochondria use oxygen and release carbon dioxide. Although oxygen is not used in anaerobic respiration, carbon dioxide is still released. Both these gases diffuse across a suitable body surface during the process of gas exchange.

Explaining the need for specialised gas exchange surfaces and ventilation

The diagram below shows four imaginary cells. This exercise investigates the effect of cell size on the efficiency of diffusion.



1. Calculate the **volume**, **surface area** and the **ratio of surface area to volume** for each of the four cubes above (the first has been done for you). When completing the table below, show your calculations.

Cube Size	Surface Area	Volume	Surface Area / Volume Ratio
2 cm cube	$2 \times 2 \times 6 = 24\ cm^2$ (2cm x 2cm x 6sides)	$2 \times 2 \times 2 = 8\ cm^3$ (height x width x depth)	24 to 8 = 3 to 1
3 cm cube			
4 cm cube			
5 cm cube			

2. Create a graph, plotting the surface area against the volume of each cube, on the grid on the right. Draw a line connecting the points and label axes and units.

3. State which increases the fastest with increasing size – the **volume** or **surface area**.

____

4. Explain what happens to the ratio of surface area to volume with increasing size.

____

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____

5. Diffusion of substances into and out of a cell occurs across the cell surface. Describe how increasing the size of a cell will affect the ability of diffusion to transport materials into and out of a cell:

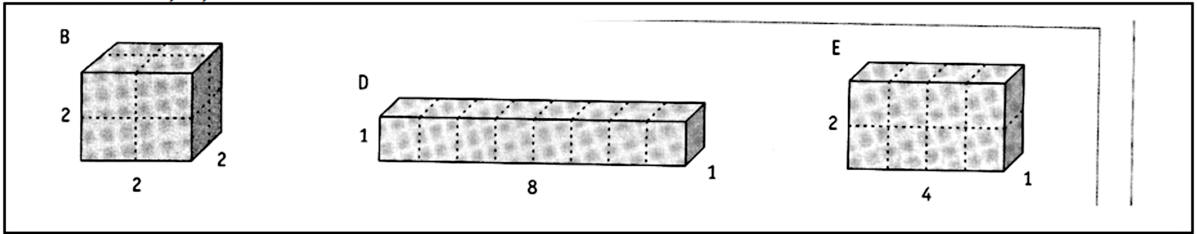
____

____

____

____

Work out the surface area, volume and surface area to volume ratio of the theoretical organisms shown below, B, D and E.



6. Present your results in the table below:

Cube	Surface Area	Volume	Surface Area: Volume
B			
D			
E			

7. What do you notice from your results?

____

____

____

8. Some organisms exchange materials across their outer body surface. What type of animals do you think this would be possible for, think about size and shape.

____

____

____

9. Land living organisms are usually unlikely to use their body surface covering for gas exchange, even if they have a high surface area to volume ratio to allow sufficient gas exchange to take place.
Why do you think they don't use their outer body surface covering?

____

____

The amount of material that an organism needs to exchange with its surroundings is proportional to its volume, but its ability to exchange material is proportional to its surface area to volume ratio. As organisms get larger their surface area to volume ratio decreases.

Larger organisms can only survive if they evolve ways of optimising the exchange of materials. Organisms can:

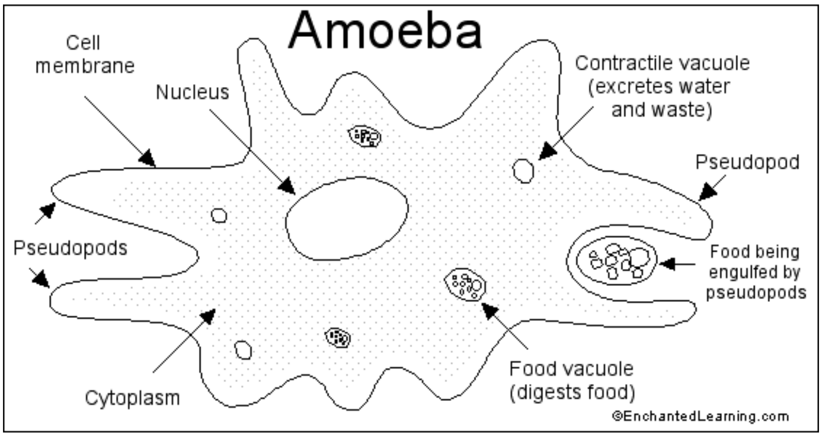
- Increase their surface area
- Make membranes as thin as possible
- Maintain a diffusion gradient using ventilation mechanisms and a circulatory system.

Gas exchange describes the exchange of gases (diffusion) across a respiratory surface, smaller organisms can rely simply on the diffusion of gases towards and away from the respiratory surface, larger organisms however, will need a ventilation mechanism / respiratory movements which use muscles to actively draw gases towards and away from the respiratory surface.

Gas Exchange in Small Organisms

The surface area to volume ratio is so large that diffusion through the body surface is sufficient to supply their needs as is the distance that those gases need to travel.

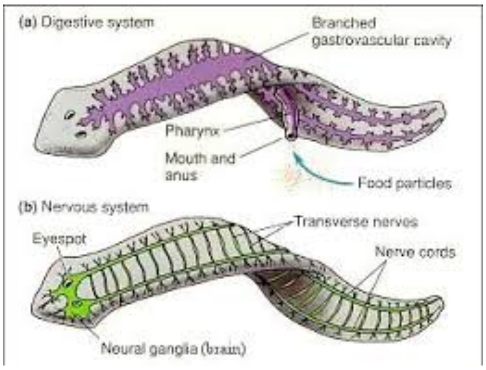
Amoeba



Amoeba lives in fresh water, which allows for the easy diffusion of nutrients. Their single celled sized means that they have a large surface area to volume ratio and this can supply all the needs for gas exchange.

Flatworms (Platyhelminthes)

Platyhelminthes exchange gases exclusively by diffusion through their body surface. This is only possible because all cells are localized relatively near to the exterior since gases diffuse cell by cell (the flat shape of these worms is a feature that allows this type of respiration).



Problems of Gas Exchange in Air and Water

Organisms that breathe air will find it easier to extract the oxygen that they need, there is **usually about 30 times more oxygen in air that in water**. It is no coincidence that the animals with the highest metabolic rates are land based and air breathers.

However, a major drawback of air breathing is **water loss**. The combination of a large surface area and moist membranes means that exhaled air is saturated with water vapour.

When you wake up in the morning and see condensation on your windows, it is likely that much of that water came from your lungs.

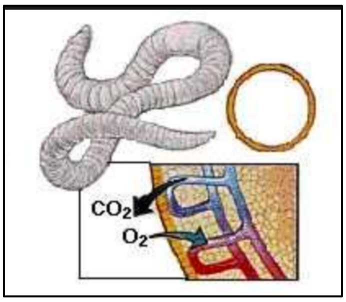
Gas Exchange in Animals
There are four types of gas exchange systems:
- *Integumentary exchange*, which occurs through the skin
- *Gills*, which exchange gases in water environments
- *Tracheal systems*, which are used by insects
- *Lungs*, which are found in land animals

All gas exchange surfaces will have the following features:

- A large surface area
- A thin short diffusion distance (often only one cell thick)
- Moist (gases can diffuse and then move into the blood)
- Will have a concentration gradient to enable rapid diffusion of gases across the surface

Earthworms – Gas exchange Across the Skin (Integumentary exchange)

Earthworms are able to use gas exchange across their skin for the following reasons:
- Are slow moving and have a low metabolic rate
- Mucus is secreted to keep the skin moist
- They have a long narrow shape with a large surface area to volume ratio
- The diffusion distance into the body is small
- They have a circulatory system and blood pigments that help to maintain concentration gradients.



Earthworms have capillaries right under their "skin." As the worms move through the soil, they loosen the soil, which creates air pockets. The worms take in oxygen from the air pockets and release carbon dioxide right through their outer surface. However, to be able to exchange gases directly with their environment, earthworms must stay moist, therefore they are restricted to damp areas.

Explain how you think a circulatory system and blood pigments will help to maintain concentration gradients:

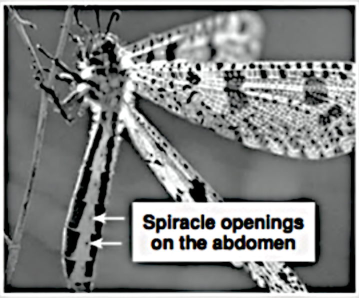
Insects – Tracheal systems

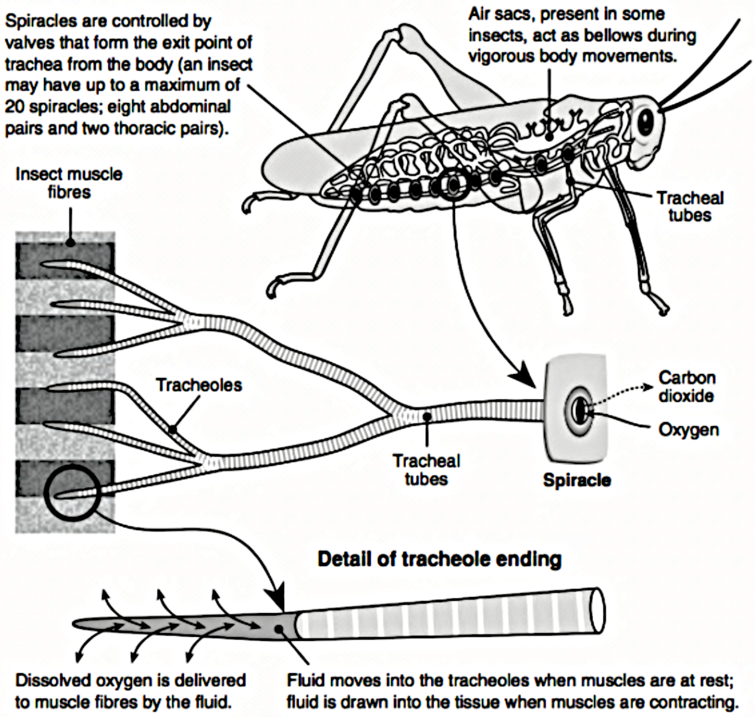
The mechanism of gas exchange in insects is in marked contrast to most other animals. Instead of being picked up by blood at the gaseous exchange surface and then transported to the tissues, oxygen passes directly to the tissues via a system of tubes called tracheoles. Every cell of an insect is a very short distance from tracheoles and therefore the diffusion pathway is short.

One advantage of gas exchange for terrestrial animals is that oxygen is proportionately more abundant in air than in water. However, terrestrial life also presents certain problems: body water can be lost easily through any exposed surface that is moist, thin, permeable, and vascular enough to serve as a respiratory membrane. Most insects are small terrestrial animals with a large surface area to volume ratio. Although they are highly susceptible to drying out, they are covered by a hard exoskeleton with a waxy outer layer that minimises water loss. Tracheal systems are the most common gas exchange organs of terrestrial arthropods, including insects. Most body segments have paired apertures called spiracles in the lateral body wall through which air enters. Filtering devices in the spiracles prevent small particles from clogging the system, and valves control the degree to which the spiracles are open. In small insects, diffusion is the only mechanism needed to exchange gases, because it occurs so rapidly through the air-filled tubules. Larger, more active insects, such as locusts (below) have a tracheal system which includes air sacs that can be compressed and expanded to assist in moving air through the tubules.

Insect Tracheal Tubes

Insects, and some spiders, transport gases via a system of branching tubes called tracheae or tracheal tubes. The gases move by diffusion across the moist lining directly to and from the tissues. The end of each tube contains a small amount of fluid in which the respiratory gases are dissolved. The fluid is drawn into the muscle tissues during their contraction, and is released back into the tracheole when the muscle rests. Insects ventilate their tracheal system by making rhythmic body movements to help move the air in and out of the tracheae.





What advantage is there in having a tracheal system with spiracles? (think about water loss)

Explain how oxygen and carbon dioxide are exchanged between the air and tissues at the end of the tracheoles in insects:

Oxygen gets directly to the tissues along these tracheal tubes for a lot of insects solely by diffusion. This may help to explain why insects tend to be quite small. However, in some species of insect gas exchange is aided by the rhythmical contractions of thorax or abdomen, ventilation. This can be seen for example in insects such as the locust where air enters through the thoracic spiracles and leaves via the abdominal spiracles. In all flying species, the muscular movements help ventilation during flight.

https://www.youtube.com/watch?v=HV60yTvy3Mk

https://www.youtube.com/watch?v=ha2kmEM1alU

Terrestrial animals (apart from insects and some spiders) possess lung for gas exchange whereas as aquatic organisms possess gills.

Gas Exchange in Fish

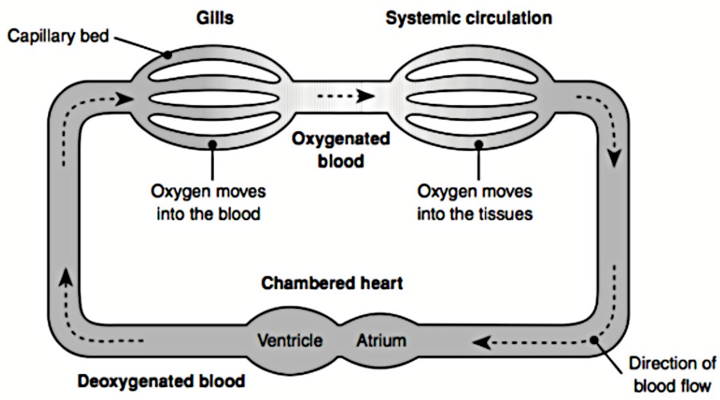
Fish obtain the oxygen they need from the water by means of gills: membranous structures supported by cartilaginous or bony struts. Gill surfaces are very large and as water flows over the gill surface, respiratory gases are exchanged between the blood and the water. The percentage of dissolved oxygen in a volume of water is much less than in the same volume of air; air is 21% oxygen while in water dissolved oxygen is about 1% by volume. High rates of oxygen extraction from the water, as achieved by gills, are therefore a necessary requirement for active organisms in an aquatic environment. In fish, ventilation of the gill surfaces to facilitate gas exchange is achieved by actively pumping water across the gill or swimming continuously with the mouth open.

Bony fish have four pairs of gills, each supported by a bony arch. The operculum (gill cover) is important in ventilation of the gills.

Cartilaginous fish have five or six pairs of gills. Water is drawn in via the mouth and spiracle and exits via the gill slits (there is no operculum).

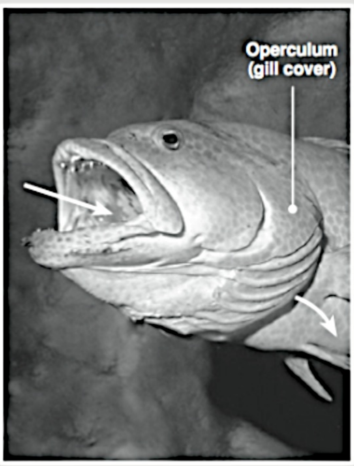
Circulation and Gas Exchange in Fish

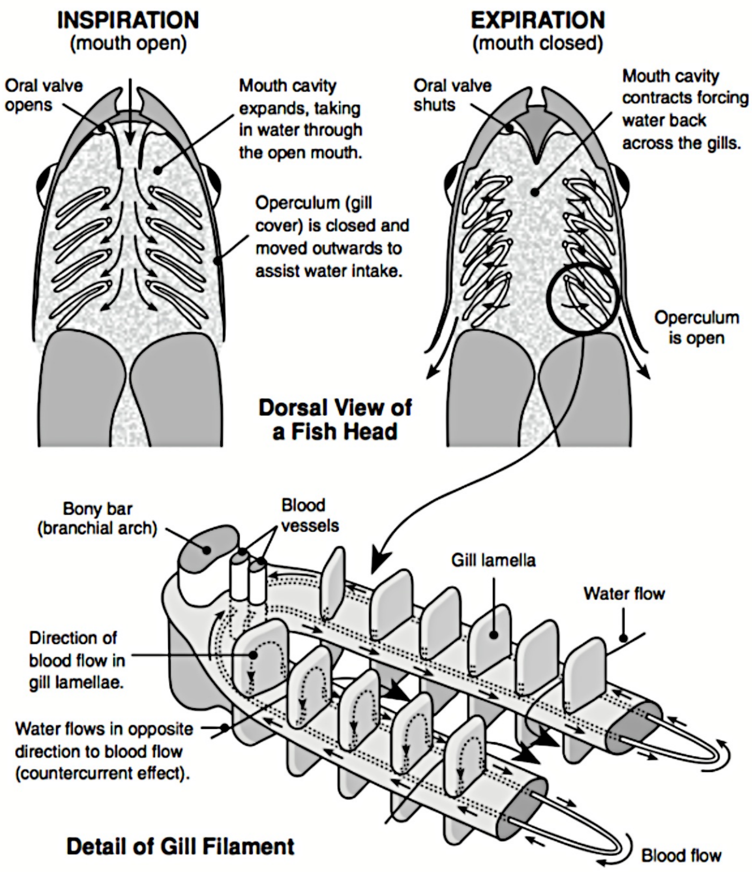
Fish and other vertebrates have a **closed circulatory system** where the blood is entirely contained within vessels. Fish have a **single circuit system;** the blood goes directly to the body from the gills (the gas exchange surface) and only flows once through the heart in each circulation of the body. The blood loses pressure when passing through the gills and, on leaving them, flows at low pressure around the body before returning to the heart. The gas exchange and circulatory systems are closely linked because the blood has a role in the transport of respiratory gases around the body.



Fish Gills

The gills of fish have a great many folds, which are supported and kept apart from each other by the water. This gives them a high surface area for gas exchange. The outer surface of the gill is in contact with the water, and blood flows in vessels inside the gill. Gas exchange occurs by diffusion between the water and blood across the gill membrane and capillaries. The operculum (gill cover) permits exit of water and acts as a pump, drawing water past the gill filaments. Fish gills are very efficient and can achieve an 80% extraction rate of oxygen from water; over three times the rate of human lungs from air.

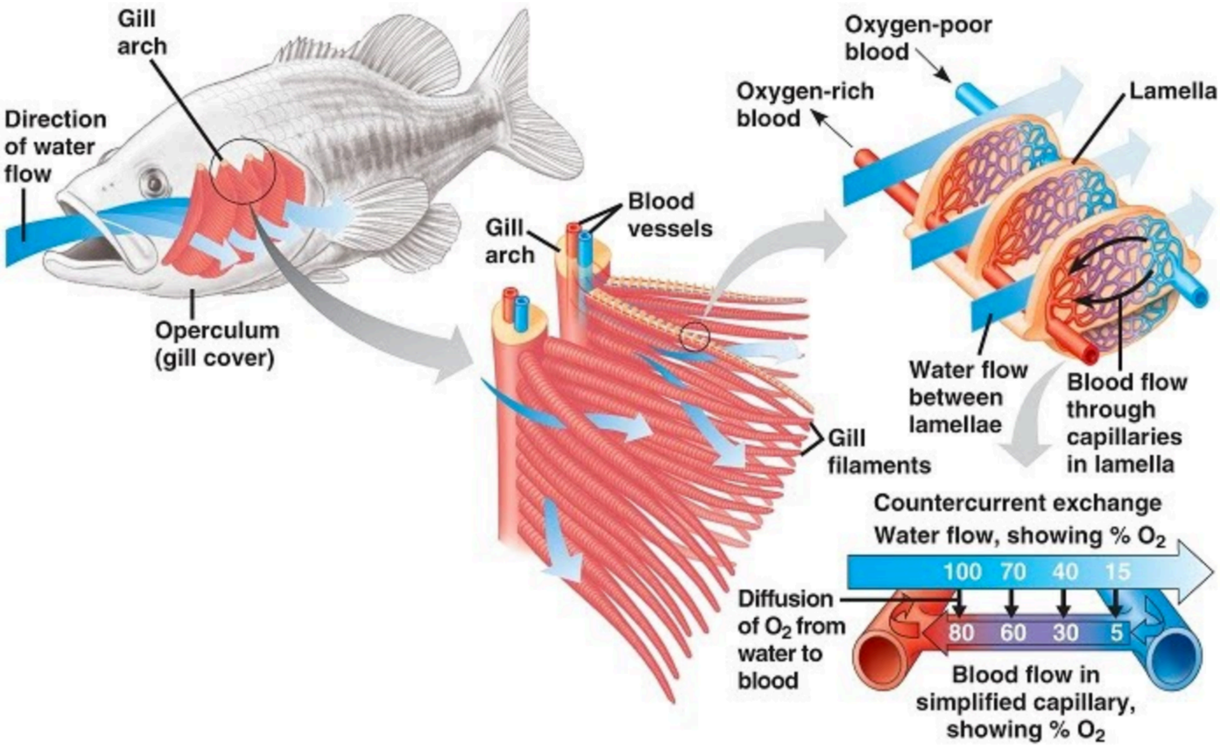




Source: C.J. Clegg & D.G. McKean (1994)

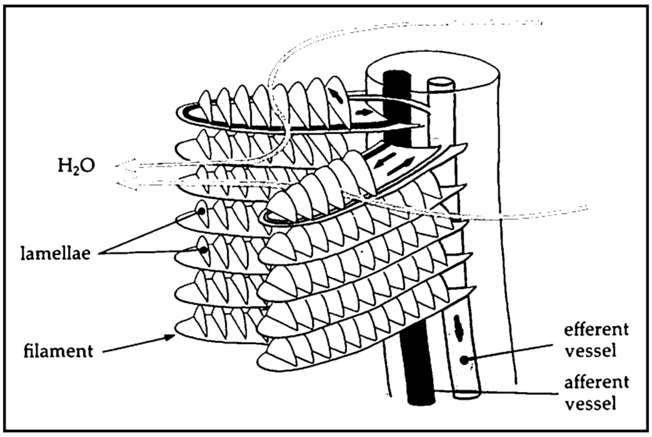
Gas Exchange in Bony Fish

Most bony fish have four gill arches and each gill arch has two rows of gill filaments.



- Identify the 4 gill arches
- Label the two rows of gill filaments on a gill arch.

Each gill is composed of many filaments increasing. Each filament is covered with lamellae, the site of gas exchange. These lamellae increase the surface area for gas exchange. The lamellae are thin and therefore ensure that the diffusion distance is short. (Out of water the gill filaments stick together and the surface area for gas exchange is reduced drastically)



Look at the diagram carefully.

The afferent vessel brings blood to the gill filaments. The efferent vessel takes blood away from the gill filaments.

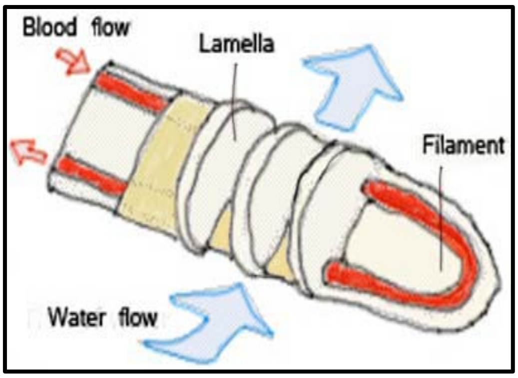
Which will have blood with higher oxygen content, the afferent or efferent vessel?

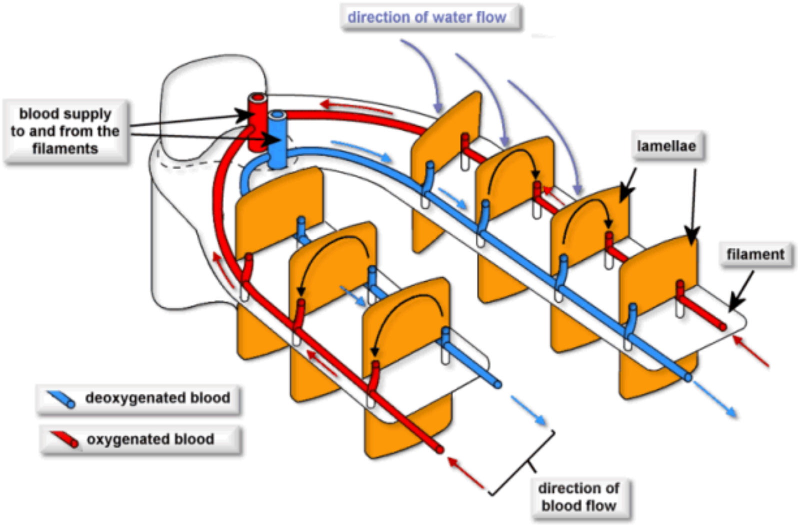
____

____

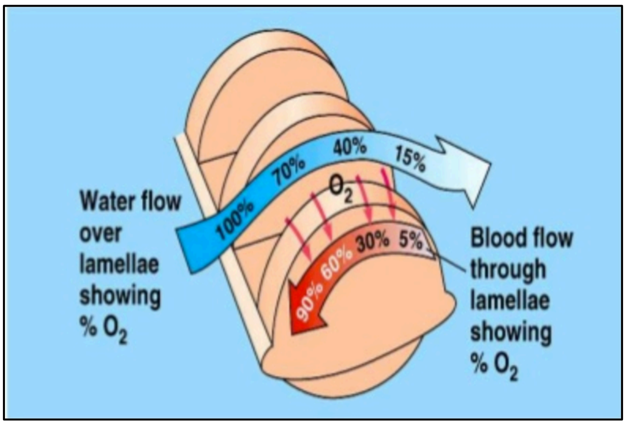
The blood flows through the lamellae in the opposite direction to the water and is what is known as a countercurrent mechanism.

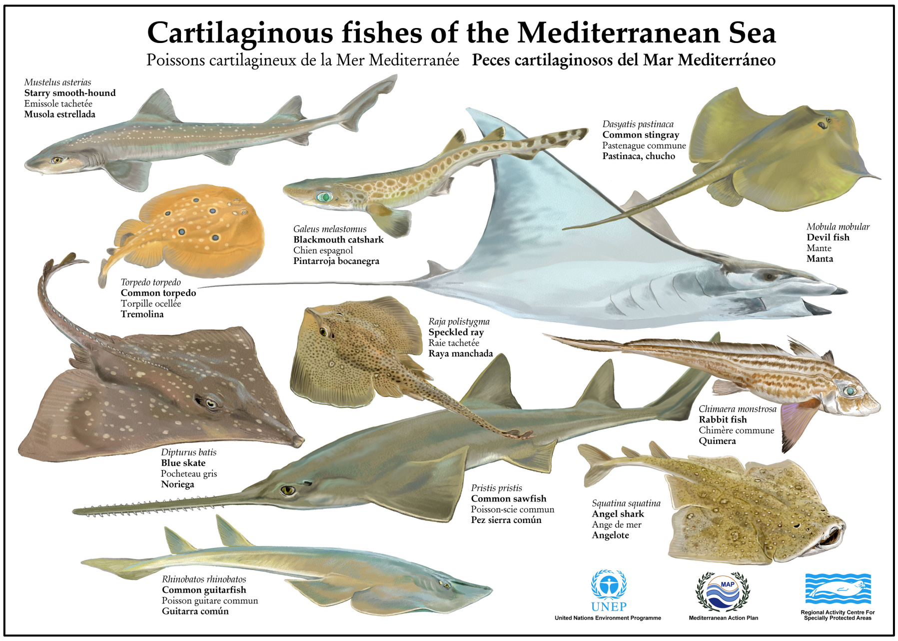
A countercurrent system ensures that there is always a diffusion gradient. Blood gathers oxygen as it flows along the gill lamellae, but it keeps on encountering fresh water that contains even more oxygen than the blood itself.





By having a countercurrent flow mechanism it allows for maximum gaseous exchange to take place.

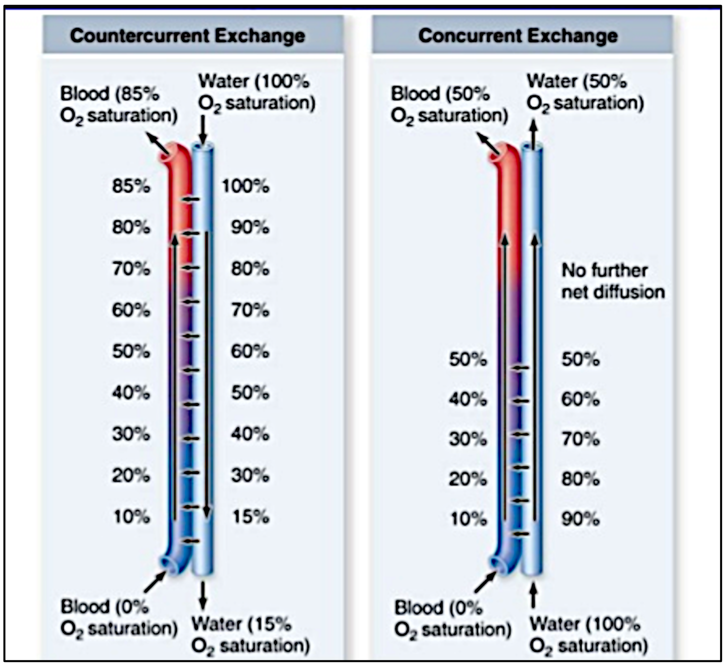


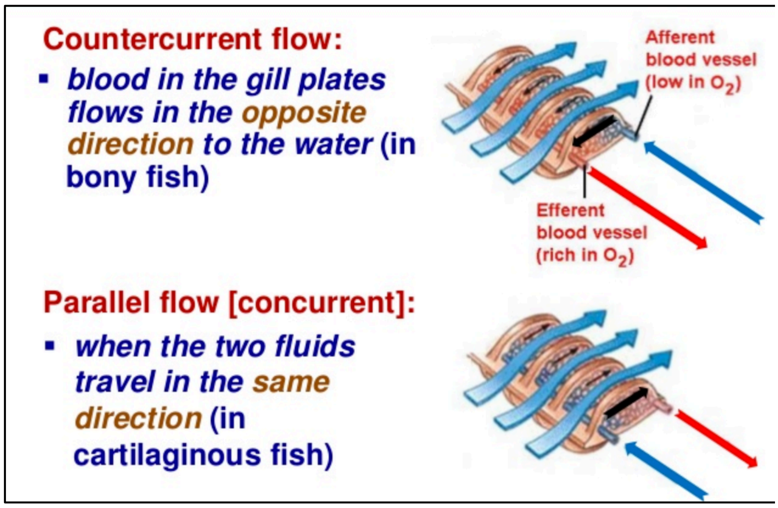


Cartilaginous fish have no bone only cartilage. An example of a cartilaginous fish is a shark or stingray.

In contrast to bony fish gas exchange takes place using a parallel flow (concurrent) mechanisms whereby the water flows over the gills in the same direction the blood flow.

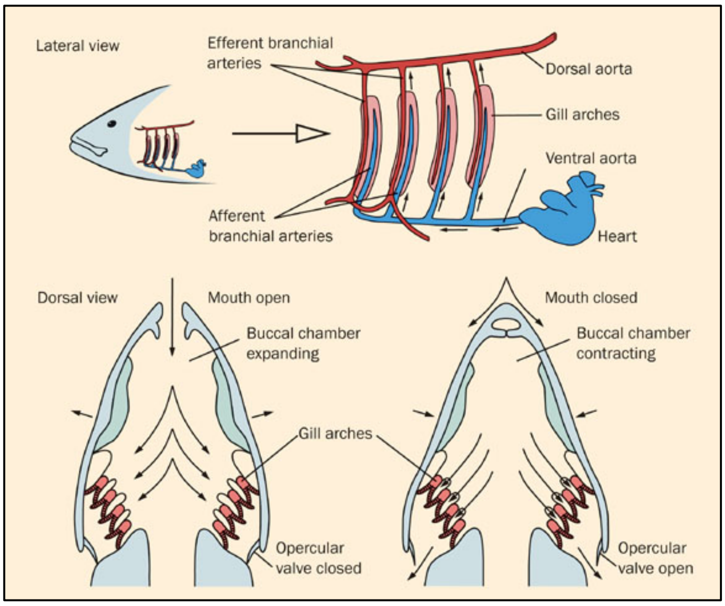
Parallel flow is inefficient. An equilibrium is reached quickly and oxygen can no longer be extracted from the water by the haemoglobin.





Ventilation in Bony Fish
Water is a dense medium with a low oxygen content; therefore, to increase efficiency it needs to be forced over the gill filaments by pressure differences so maintaining a continuous flow of water.

To increase efficiency of gas exchange water needs to be forced over the gill filaments to ensure a constant supply of fresh water.



The cavity of the mouth is referred to as a buccal cavity.

The cavity with the gills is called the opercular cavity.

The flap covering the gills is called the operculum flap.

Inspiration and Expiration

Complete the table to show how water is forced over the gills in expiration.

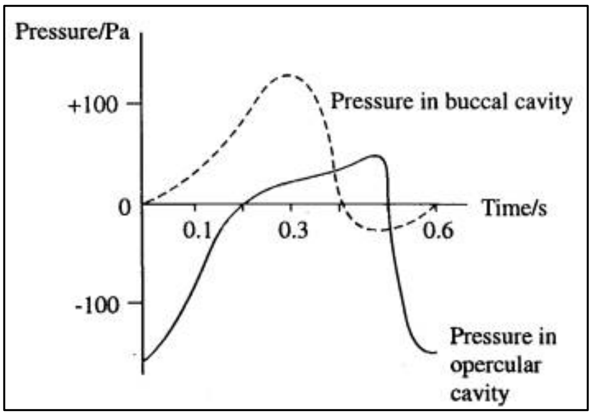
Inspiration

Mouth	**Opens**
Operculum flap	**Closes**
Floor of cavity	**Lowered**
Volume	**Increased**
Pressure	**Decreased**

Expiration

Mouth	
Operculum flap	
Floor of cavity	
Volume	
Pressure	

The figure below shows the pressures measured inside the buccal and opercular cavities of a bony fish during normal breathing. Identify with reasons the part of the graph in which:



a. water enters the mouth

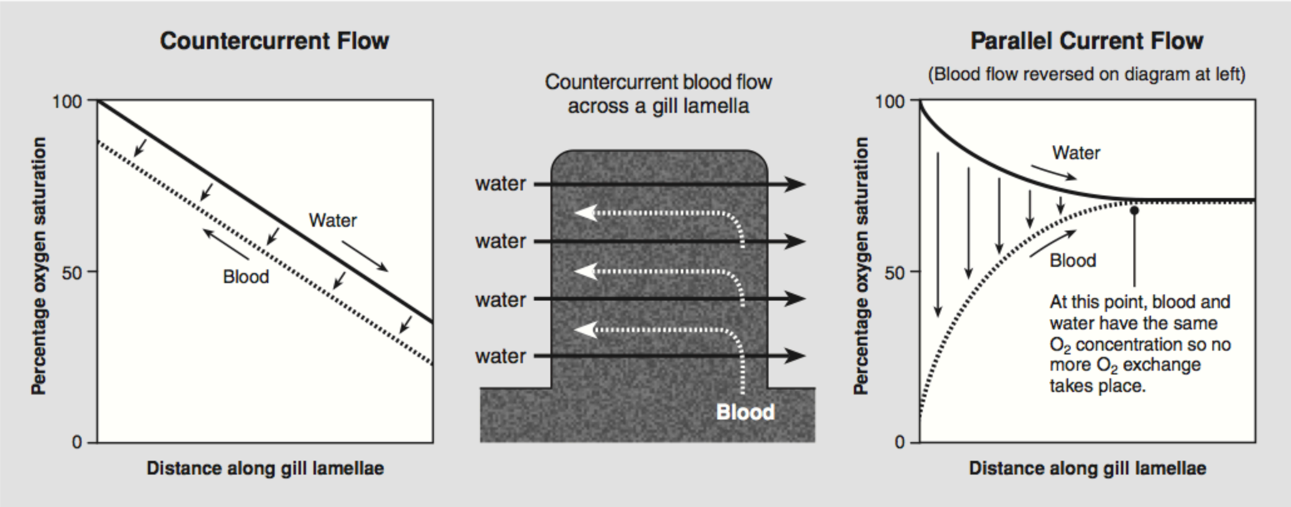
b. water is pushed from the mouth to the opercular cavity

c. the mouth closes

d. water is pushed over the gills

e. The opercular valve is open

The structure of fish gills and their physical arrangement in relation to the blood flow ensure that gas exchange rates are maximised. A constant stream of oxygen-rich water flows over the gill filaments in the **opposite** direction to the direction of blood flow through the gills. This is termed **countercurrent flow** (below, left). Blood flowing through the gill capillaries therefore encounters water of increasing oxygen content. In this way, the concentration gradient (for oxygen uptake) across the gill is maintained across the entire distance of the gill lamella. A parallel current flow would not achieve the same oxygen extraction rates because the concentrations across the gill would quickly equalise (below, right).



1. Identify three features of a fish gas exchange system (gills and related structures) that facilitate gas exchange:

   (a) ______

   (b) ______

   (c) ______

2. (a) Explain how the countercurrent system in a fish gill increases the efficiency of oxygen extraction from the water:

   ______

   ______

   (b) Explain why parallel flow would not achieve adequate rates of gas exchange: ______

   ______

3. (a) Explain what is meant by ventilation of the gills: ______

   ______

   (b) Explain why ventilation is necessary: ______

   ______

   (c) Describe the two ways in which bony fish achieve adequate ventilation of the gills:

   Pumping (mouth and operculum): ______

   ______

   Continuous swimming (mouth open): ______

   ______

   (d) Suggest why large, fast swimming fish (e.g. tuna) will die in aquaria that restrict continuous swimming movement:

   ______

   ______

4. In terms of the amount of oxygen available in the water, explain why fish are very sensitive to increases in water temperature or suspended organic material in the water:

   ______

   ______